New Parameters to Characterize Internal Stresses via Barkhausen Noise

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Abstract. While predicting internal stresses in steels via Barkhausen Noise (BN) along with high sensitivity there exist several influencing factors, which arose uncertainties and falsify measurement results. These factors are micro structure, surface non uniformity, surface decarburization, etc. In this paper we deal with some new opportunities to minimize uncertainties in stress prediction. The first approach is based on the observation, that, while increasing the amplitude of a driving magnetic field, the BN appears step-wise at some “field of start” (FoS) value. This value is approved to be weakly dependent on some influencing factors. The second approach is based on extracting a specific information about stresses from the diagrams of BN variation through angular and amplitude scanning of driving magnetic field value respectively. The experiments have been made using “Introscan” analyzer.

Introduction

While predicting internal stresses in steels via Barkhausen Noise (BN) along with high sensitivity there exist several influencing factors, which arose uncertainties and falsify measurement results. These factors are micro structure, surface non uniformity, surface decarburization, etc. Many attempts have been undertaken to solve the problem: introducing so called “jumpsum” parameter instead of BN intensity [1], parallel measurement of magnetic and acoustic BN [2], stabilization of magnetic flux value in the magnetizing circuit [3], and so on. In this paper we deal with some new opportunities to minimize uncertainties in stress prediction.

Besides of the estimate of the construction integrity, improvement of stress NDE precision is motivated by many purposes. Among them: development of easy reproducible stress gauge, competitive to well known strain gauge; indirect measurement of intrinsic pressure in pressure vessels; development of MBE-based sensors for load and weight measurement. It is clear that in order to acquire for better precision of stress measurement techniques it is necessary to consider the tensor-like nature of stresses, to make efforts for suppressing a concomitant noise and influencing factors, like microstructure and chemical inhomogeneity; to search for new parameters with improved robustness with regard to noise.

In our later works some elaborations have been demonstrated, directed to the stress measurements with depth resolution [3], providing for temperature stability, microstructure statistical analysis, basing on the reconstruction of the probability density distribution function of magnetization micro volumes. The measurement of statistic parameters of BN needs precise and comprehensive instruments. Most of the existing use the effective voltage of BN to characterize its integral intensity in the specimen under uni-directional magnetization. The instrument “INTROSCAN” is developed to improve measurement characteristics targeting to make the step from stress qualitative assessment to stress measurement. This transition is as well grounded on using the angular and amplitude scanning of driving magnetic field and its feed back control to provide stabilization of magnetic flux density in the material under test. We introduce also the new magnetic noise parameter – field of start (FoS) to control the stress selective sensitivity and propose some improvements in BN measuring procedure to facilitate stress measurement in the material with small microstructure deviations.

1. Field of start measurement

It is well known that the magnetic parameter -Barkhausen noise intensity - is sensitive to internal stress variations in steel and cast iron. The sign of the sensitivity is the same as the sign of material's magneto-striction constant. Thus the magnetization field value also influences upon the sensitivity and should be optimized while setting magnetization parameters. Fig. 1 is the illustration of the stress dependence of BN intensity at varied magnetization field amplitudes for low allow 30HGSNA steel in the quenched and tempered condition. The diagrams are acquired with the help of BN analyzer "Introscan".

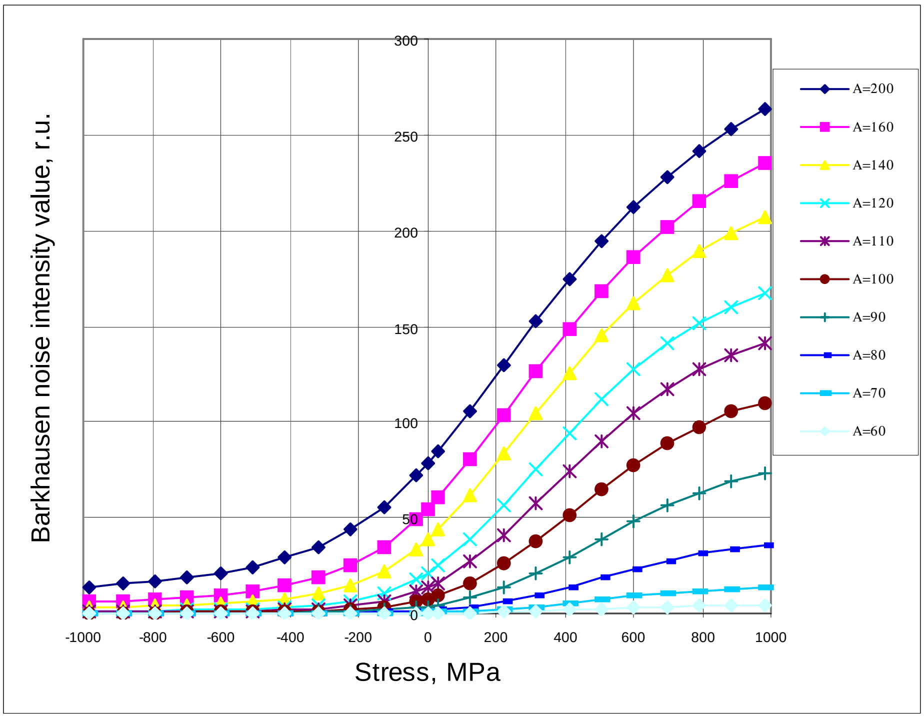

Fig. 1. Experimental single-axis stress dependence of BN intensity at automatically varied magnetization current amplitudes (in mA) for low allow 30HGSNA steel in the quenched and triple tempered condition.

As is usual, the sensitivity to compressive stresses is much weaker than that to tension. This circumstance is often the obstacle to perfect measurement of compressive stresses, e.g. in rod-shaped design members. Measurement of the FoS parameter with the help of "Introscan" enables the control over selective sensitivity to compression. Under FoS parameter we will understand the magnetization field amplitude value giving start to BN generation of selected threshold intensity value. Fig. 2 shows the dependence of FoS parameter over stress value for the same as at Fig. 1 steel ranked for different values (in r.u.) of BN threshold intensity values. The presence of optimal threshold value of BN intensity is a common feature of diagrams of this type.

2. Angle scanning of driving magnetic field

It is known that BN Angle Diagrams (AD) give new information on the anisotropy condition in the material under test. The special tetra-pole BN sensor and its control system (Fig.3) are developed to provide fast and perfect measurement of anisotropy behavior of stressed and textured structures. The tetra-pole sensor includes the assembly of two self-perpendicular electromagnets with pole pieces. The magnetic flux in each electromagnet is created by its own magnetizing coils respectively 1.1, 1.2 and 2.1, 2.2 respectively. The coils are fed by common-mode voltage from the control generator, controlled by embedded PC. The controller controls the amplitudes values of the sinusoidal currents in four coils respectively. Two feed back systems, controlled by the currents from additional coils 1.1F, 1.2F and 2.1F, 2.2F respectively in each channel X or Y, provide for the stable magnetic flux values independently on magnetic properties of the material under test and lift off. Therefore in the probe's central part, where the flexible pick-up sensor 3 is installed, the applied magnetic field vector will swing according to amplitude values in all four coils. So the BN measurements are implemented under a given applied magnetic field or magnetic flux values. The display embedded into the instrument represents the angle dependence of BN intensity in one of two selected modes with the corresponding diagram. Measurement, recording and plotting of AD with tetra-pole sensor and Introscan is easy and fast. Some examples of AD of BN intensity are shown in the Fig. 4 for the sheets from transformer steel in the random-oriented and textured conditions respectively. The deflection of the random-oriented diagram from the circle shows the presence of residual texture in the sheet. The texture direction is very clear.

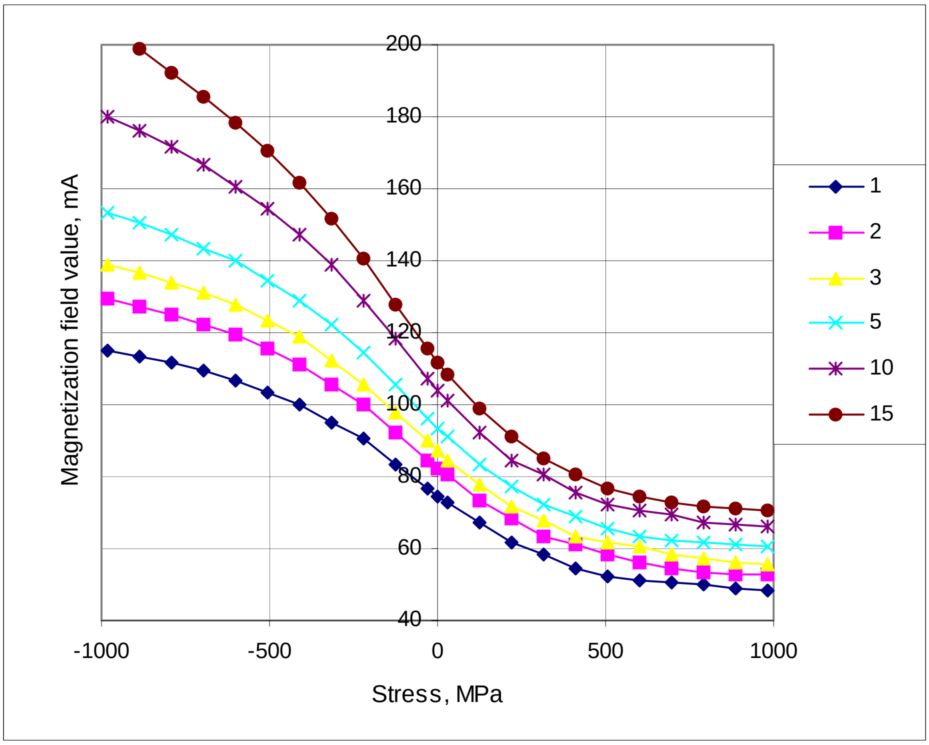

Fig. 2. Dependence of Field of Start parameter over stress value for low allow 30HGSNA steel in the quenched and triple tempered condition ranked for different values (in r.u.) of BN intensities

The Series of experiments have been provided with the high strength low alloy steel 300M in the condition after heat hardening and low temperature drawback. In this condition the yield strength was 2176 Mpa. The plate 250x35x5,5 mm was then fine grinded and polished. Then it was subjected to cantilever bending by tension and compression up to the yield strength point like is shown in fig 5. Fig 5 represents some selected AD of BN intensity under different stress values applied to the specimen surface. The left block of diagrams illustrates the AD in the plate after step-wise tension, while the right block – after compression. Both blocks contain the diagrams with zero level stresses, while two other show AD with growing up and dropping stresses respectively. The stress values are shown in the diagrams legends.

It is interesting to point out that the product spaces along direction close to 45^0 are clearly defined in the diagrams. They coincide with the easy shear direction in the uni-axial loading mode.

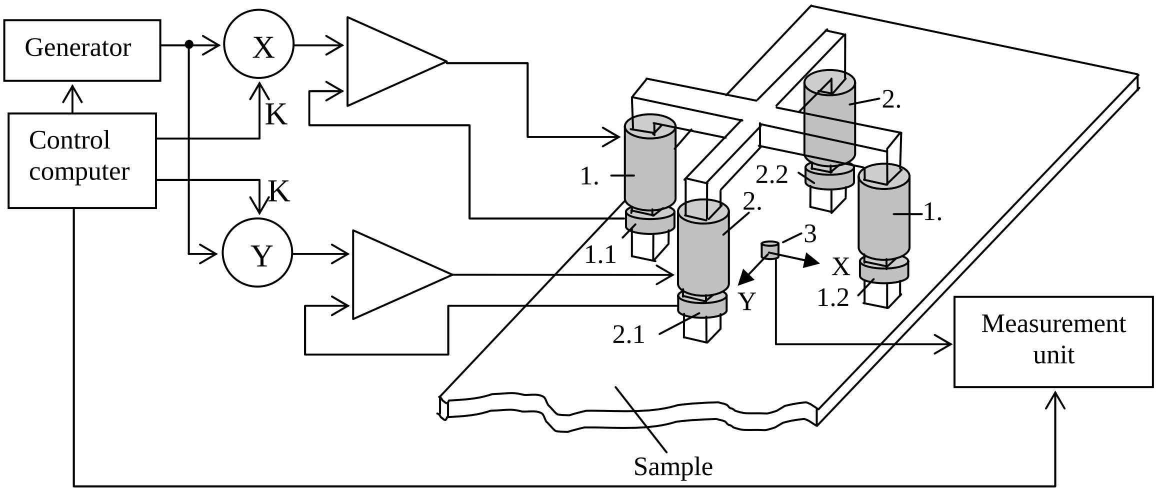

Fig. 3. Tetra-pole probe, established on a plate, and the block diagram of the control system. 1.1; 1.2 - Electromagnet coils "X", 2.1; 2.2 - Electromagnet coils "Y", 1.1F; 1.2F - Feed back coils "X", 2.1F; 2.2F - Feed back coils "X", 3 - Pick up coil. A - location of the jammed end of the plate, subjected to bending.

3. Further investigation of the magnetic field value scanning diagram

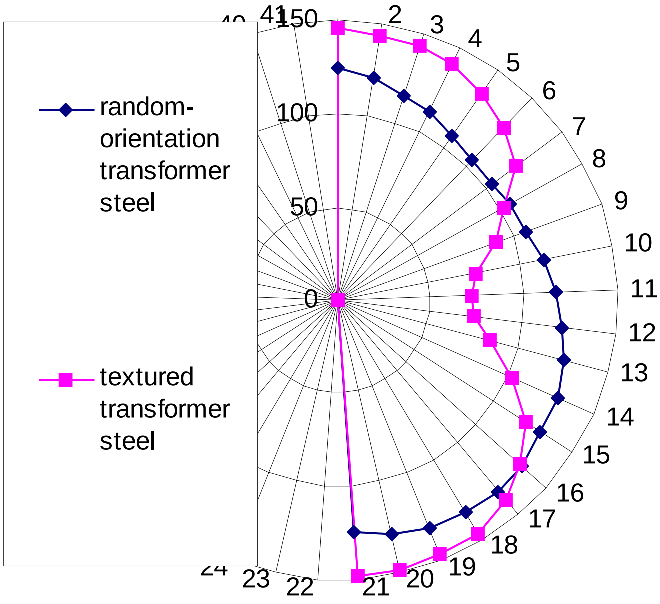

Fig.4. Angle diagrams of BN intensity for random-oriented and textured transformer steel, recorded by Introscan with tetra-pole probe. The deflection of the random-oriented diagram from the circle shows the presence of residual texture in the sheet.

“Introscan” provides for automatic on-line plotting of BN intensity – magnetic field value ($F_n (H)$) diagrams, which otherwise need to use time-consuming procedures. The non linear diagram shapes carry an important information on the kinetics of irreversible magnetization processes in a material under test, namely irreversible susceptibility. The differential susceptibility is characterized by the derivative $\partial F_n / \partial H$. We investigated some parameters of the experimental function $\partial F_n / \partial H(H)$ to have as its object to find out parameter with higher selectivity to stress variations in materials with varying microstructure. The selective behavior of one of them, named “gutter” (G_n), is described below. Fig. 6 shows the “gutter” logarithm, *logG,* dependence on the single-axis stress values in steel 30HGSNA (the analogue of steel 300M) . The diagram is close to similar in the compression and tension regions respectively. The sensitivity of *logG* parameter to stress variation is high enough and the relation $logG_{min}/ logG_{max}$ parameters in the range of stress variations of approximately $\pm\sigma_y$ (yield strength) is close to 2,5.

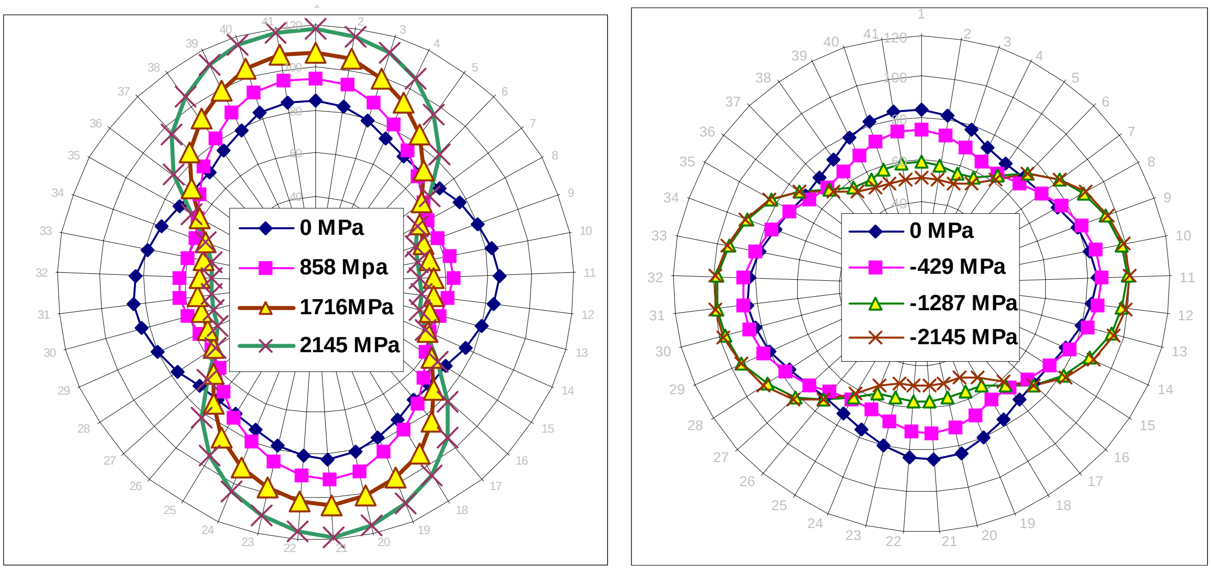

Fig.5. Directional diagrams of BN under different applied bending deformation of steel 300M plate: the functions of BN intensity upon a direction of excitation magnetic field vector. Vertical axis on the diagrams coincides with the longitudinal plate axis. Left diagram – tension, right – compression. The product spaces along direction close to 45^0 are clearly defined in the diagrams

Let's now estimate the selectivity of this parameter to stress variations. Under the selectivity we understand the sensitivity of *logG* parameter to stress variations against the background of variations of material treatment conditions, accompanied by changes in microstructure, plastic deformations, etc. For this the specimens were acquired after different heat, machine and cold rolling treatment, which are common for this high strength low allow martensite steel. The treatment conditions are clear from Table 1 and explanations below.

Table 1. Variations of *logG* parameter due to changes in 30HGSNA steel treatment conditions.

Treatment conditions		F	F+A+M+Q	F+A+M+Q+T	F+A+M+Q+T+G+T	F+A+M+Q+T+G+T+SB	F+A+M+Q+T+G+T+V		F+A+M+Q+T+G+T+V+T	
Sample No.		22	3	4	10	12	13	14	16	17
Log "gutter" value (r.u.)	bisquare(B)	0,06	0,03	0,04	0,06	0,03	0,05	0,07	0,09	0,06
	Log B	-1,22	-1,52	-1,4	-1,22	-1,52	-1,3	-1,16	-1,05	-1,22
	polinom(P)	0,06	0,03	0,06	0,04	0,03	0,06	0,08	0,08	0,06
	Log P	-1,22	-1,52	-1,22	-1,4	-1,52	-1,22	-1,1	-1,1	-1,22

The marking of the treatment conditions, used in Table 1 are as follows:
F – forging; A – annealing; M – mechanical treatment; Q – quenching from 900^0C; T – tempering at $270\text{-}300^0$C; G – grinding; SB – shotblast surface treatment; V – vibro cold rolling. Bisquare and polynomial approximations have been used for the approximation of experimental data to calculate finally the "gutter" value. The table shows that while changing the treatment conditions of the specimens the variations of the "gutter" parameter are very small. All obtained variations are kept within the mean values of –1,285 with standard deviation 0,157 (about 12%).

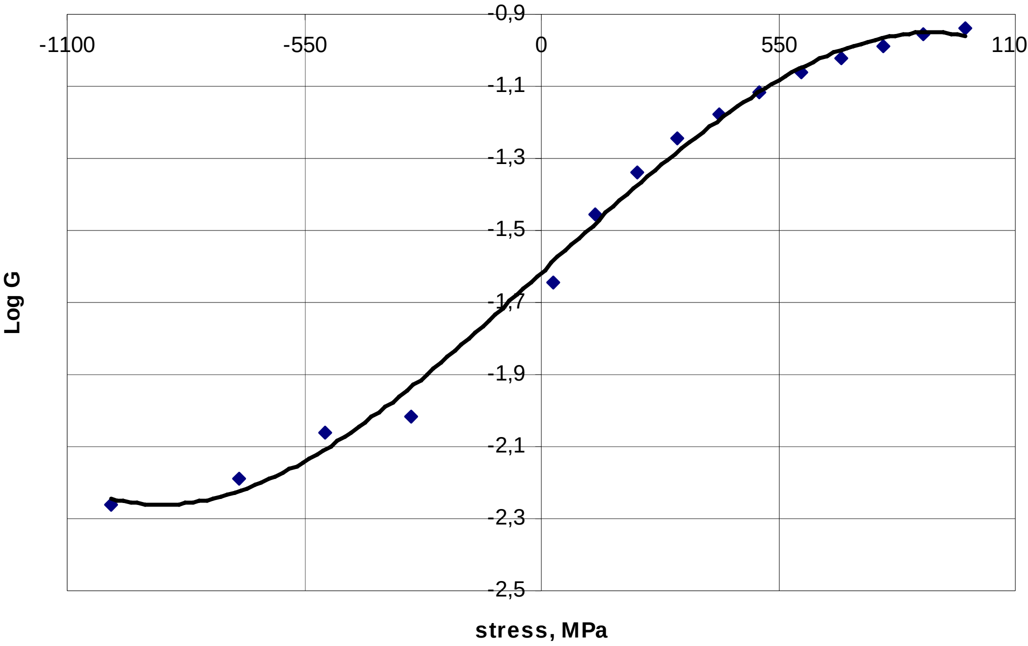

Fig. 6. Experimental dependence of the magnetic noise “gutter” logarithm via bending stress values in the plate of low alloy 30HGSNA steel in the quenched and triple tempered condition.

Conclusion

1. The sensitivity of Barkhausen noise to both stress and microstructure variations in the ferromagnetic material is well known. Some parameters, alternative to usually used Barkhausen noise intensity, have been investigated targeting to reach high sensitivity to stress variations with simultaneous low sensitivity to the changes in material treatment conditions.
2. The set of three parameters are recommended to optimize measurement facilities, namely: field of start, angle diagrams of magnetic noise and new “gutter” parameter, which stress selectivity is investigated and approved with regard to high strength low alloy steel 30HGSNA (analogue to steel 300M).

References

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